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National Ignition Facility: Drive Diagnostic Kinematic Mount Assy Plate System Characterization, Alignment & Installation

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National Ignition Facility:
Drive Diagnostic Kinematic Mount Assy Plate System Characterization, Alignment & Installation

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Abstract:

The NIF (National Ignition Facility), a program of the U.S. Department of Energy's National Nuclear Security Administration (NNSA), will focus the intense energy of 192 giant laser beams on a BB-sized target filled with hydrogen fuel, fusing the hydrogen atoms' nuclei and releasing many times more energy than it took to initiate the fusion reaction. NIF a facility one football field wide and two football fields long NIF could be considered one of metrology's "*wonders of the world*" because of the stringent precision alignment of mechanical components; optics; and subsystems. In addition to a precision network accurate to three hundred microns 3sigma over the entire facility.

Of these subsystems are the many diagnostics producing enormous amounts of data before and during and after a shot; shots lasting only two millionth of a second. One such diagnostic is the Drive Diagnostic (DrD). The purpose of the DrD is to measure the power and wavelength of the 3Ω light of all 192 beams entering the 10m diameter spherical target chamber by sampling off a fraction of a percent of energy.

The DrD is installed indirectly onto the target chamber beam ports (each port directing 4 of the 192 beams.) Each DrD has a minimum of 12 precision optics and sensors per beam, over ~2300. The DrD optic/sensor assemblies called LRU's (Line Replaceable Units) are affixed to the chamber on the calorimeters using kinematic mount plate assemblies (KMA); totaling 96 KMA's for the 48 ports, with each assembly having 12 kinematic mounts on which to mount the LRU's. There are 8 LRU's per port, 4 on top and 4 on the bottom. The challenge was to devise an alignment strategy for installing the KMA's onto the chamber pre-aligned within 250 microns to integrate with pre-aligned LRU's. One obstacle for the strategy was the imperfections in the positioning of the calorimeters the KMA's are bolted to which were in a Spherical configuration in a Cartesian coordinate system. Other obstacles were working with data in both a Cartesian and Spherical coordinate systems and quality-assuring & quality-controlling the compiling of the as-built data and the design data to insure proper coordinate calculations for positioning. Using data collected from a complement of CMM and laser tracker metrology it was possible -through reverse engineering- to process the data for presetting the kinematic mounts and lateral interfaces to produce a "plug-&-play" installation. This presentation will explain the mechanical configuration of the alignment strategy; how the data was collected; what steps and controls were used to quantify the pre-alignment coordinates along with the data quality controls insuring the quality and mitigation of any errors of the data compiled.

INTRODUCTION

The National Ignition Facility (NIF), a program of the U.S. Department of Energy's National Nuclear Security Administration (NNSA), will focus the intense energy of 192 giant laser beams on a BB-sized target filled with hydrogen fuel, fusing the hydrogen atoms' nuclei and releasing many times more energy than it took to initiate the fusion reaction. NIF is a facility one football field wide and two football fields long. NIF could be considered one of metrology's "*wonders of the world*" because of the stringent precision alignment of mechanical components; optics; and their subsystems. In addition, NIF has a precision network accurate to three hundred microns 3sigma over the entire stadium size facility.

Of these subsystems are the many diagnostics producing enormous amounts of data before, during and after shot operations; shots lasting only two millionth of a second. One such diagnostic is the Drive Diagnostic (DrD). The purpose of the DrD is to measure the power and wavelength of the 3Ω light of all 192 beams entering the 10m diameter spherical target chamber by sampling off a fraction of a percent of energy.

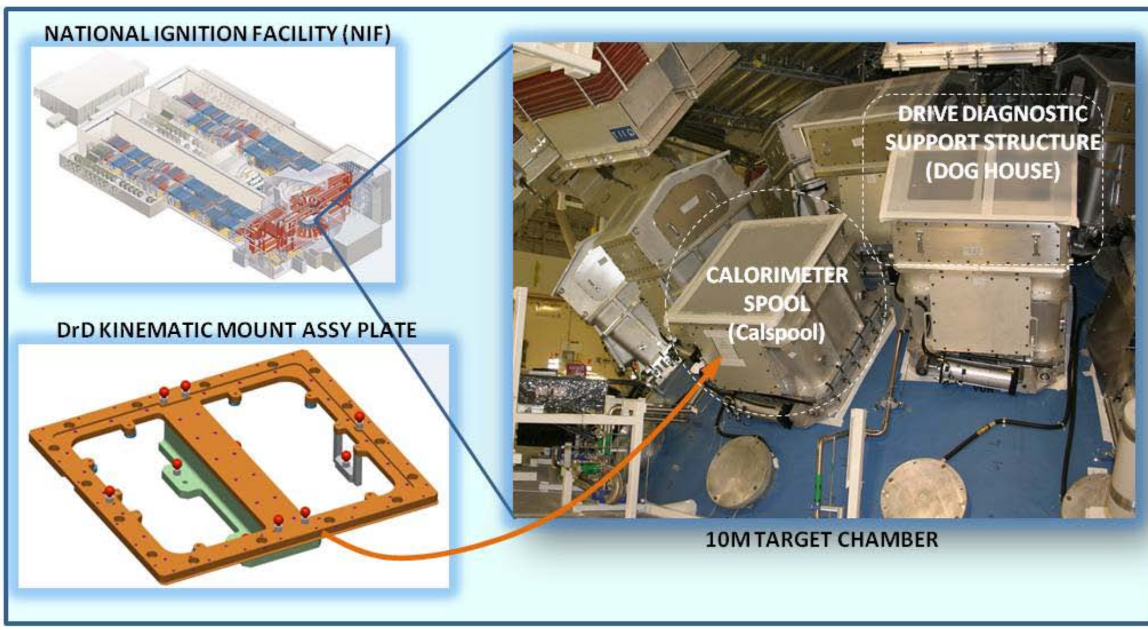

Figure 1

The DrD is installed indirectly onto the target chamber beam ports (each port directing 4 of the 192 beams, 48 ports in total.) Each DrD has a minimum of 12 precision optics and sensors per beam, totaling ~2300. The DrD optic/sensor assemblies called LRU's (Line Replaceable Units) are affixed to the chamber using kinematic mount assembly plates (KMA plate) attached to Calorimeter Spools (Calspools) totaling 96 KMA plates for the 48 ports with each KMA plate having 12 kinematic mounts on which to mount the LRU's. There are 8 LRU's per port, 4 on top and 4 on the bottom (two for each beam,) see figures 3 & 4.

NIF DRIVE DIAGNOSTICS

1. Mechanical Configuration

NIF is formally in a Cartesian Coordinate System (CCS). All NIF mechanical assemblies are driven by Optical Configuration Drawings (OCD) with the mechanical assemblies designed around the positional and alignment requirements these drawings dictate for optic placement. On a large project such as NIF there will be -from time to time- a location where measurements and coordinate analysis are precarious at best. NIF's location is at the ten meter diameter spherical target chamber.

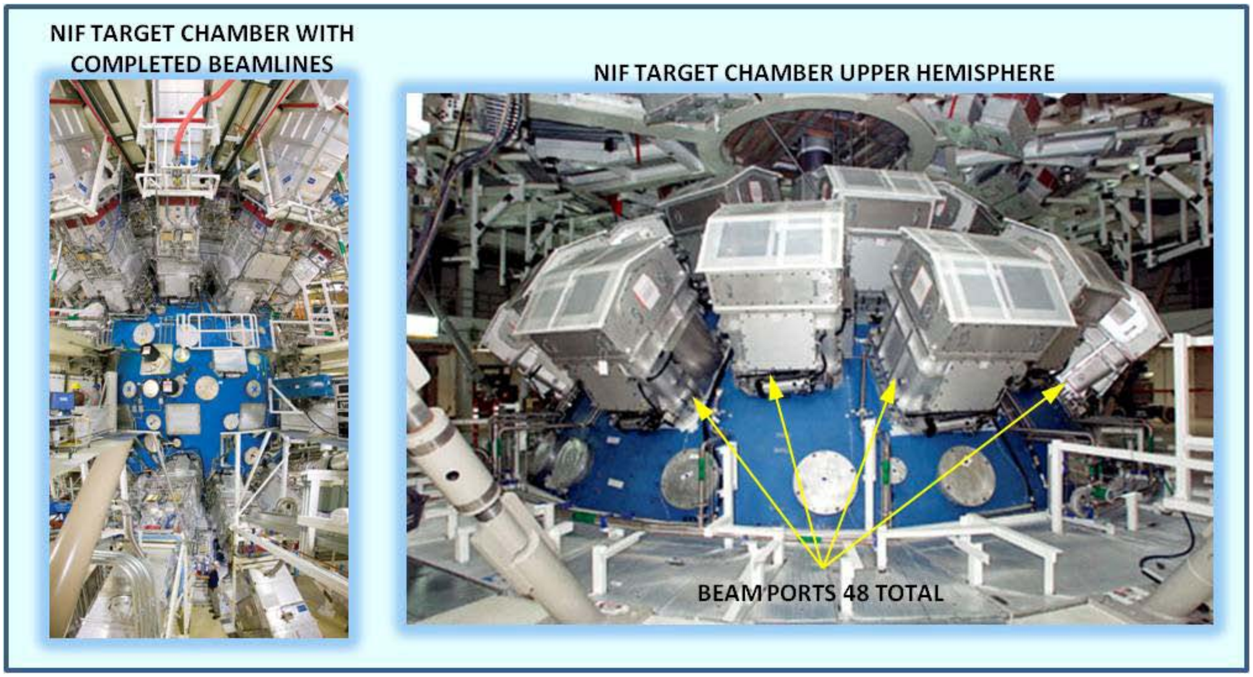

Figure 2

Formally assembled and designed in a CCS, it would have been irrational not to employ a Spherical Coordinate System (SCS) integrated to the CCS because of the spherical shape of the target chamber. Moreover NIF also employs hundreds of lower level Parametric Coordinate Systems termed Local Coordinate Systems (LCS). What is meant by parametric is simply the NIF CAD model has a top assembly which is called "NIF Project" it is the top level assembly, in this top level reside hundreds perhaps thousands of Local parametric CS's. When a subassembly is started for design the CS for that specific location is "passed down" from "NIF Project" to that subassembly –to build around that CS. Once it's completed it is then "copied up" back to "NIF Project" and integrated into the top assembly. Upon release of a new revision the top assembly is then "regenerated" and the components and all its features are now linked "parametrically" together. This was how tens of thousands of NIF installation coordinates were quality controlled and generated to an accuracy of 1 micron, moreover this was how NIF could be certain coordinates generated from the top assembly down to the subassemblies are one hundred percent reliable. The coordinate generation for installation of the DrD employed this compilation and use of the parametric CS's just described.

2. The Goal of the Installation

The goal of the installation was an alignment of a precision optical subassembly -the DrD LRU’s- onto an improperly installed upper assembly Calspool mounted onto the 10m diameter spherical target chamber to within ±125 microns flawlessly 96 times, see figure 3.

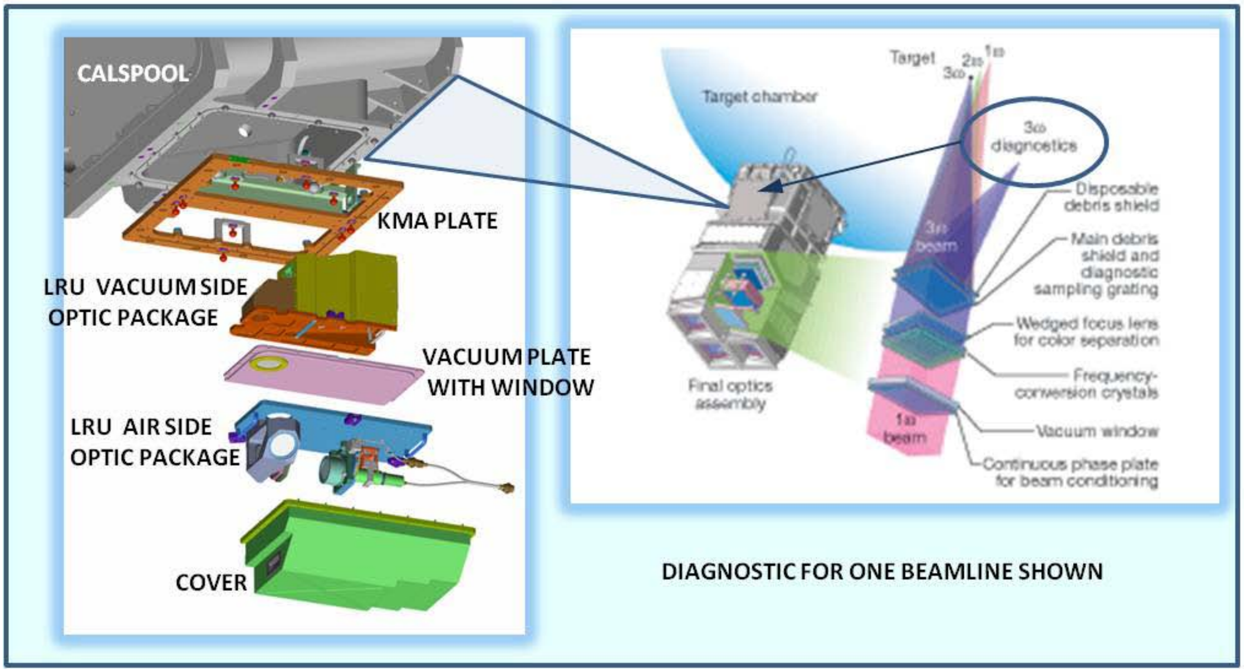

Figure 3

The Calspool imperfection compounding the precision installation was the fact the Calspool interfaces (spacers) attached to the target chamber (48 in total) were machined incorrectly. This corrective spacer designed to machine out profile and plane imperfections was intended to create an orthogonal vector from the centerline of the Calspool to the center of the chamber. At the time when the error was mitigated (to prevent beam clipping) it was believed the modification was sufficient and understood to pose no future problems to subsequent subassembly integrations. This conclusion would later prove false.

The Calspool mitigation at the time was adequate to overcome beam clipping and pointing concerns; in summary it minimized the maximum errors with respect to clear aperture; which in the Local CS defined the “X & Y” axes to be critical leaving the ‘Z’ understood to be the soft axis.

Later it was discovered ‘Z’ was in fact not soft but also critical to the DrD because the DrD would be housed inside the Calspool. The DrD source energy -for sampling- is provided by the Wedged Focal Lens (WFL; pronounced “wiffle”), see figure 4.

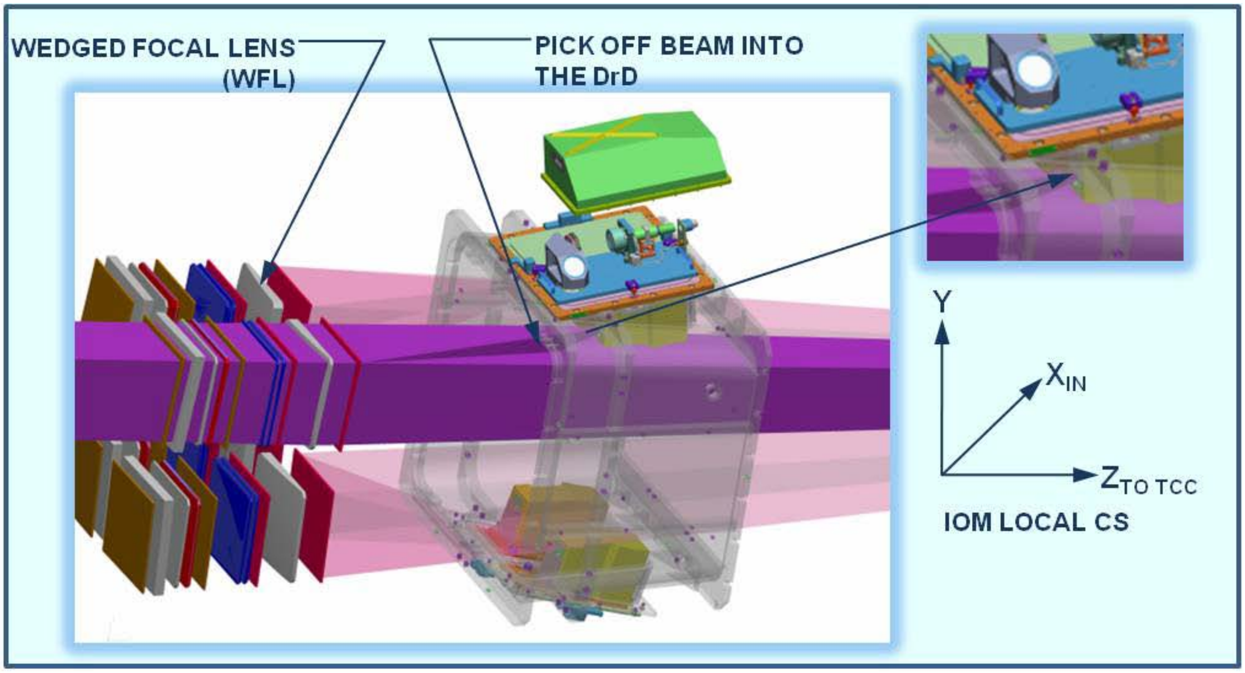

Figure 4

The focal distance from the WFL to the DrD was critical to the pointing and centering of the energy to hit the DrD optics accurately in order for the DrD to get the energy required and equally important not damage the diagnostic package components. The WFL is part of the Integrated Optics Module (IOM) hard mounted to the Drive Diagnostic Support Structure (DDSS, aka. "The Doghouse") which is then hard mounted to the Calspools, see figure 5.

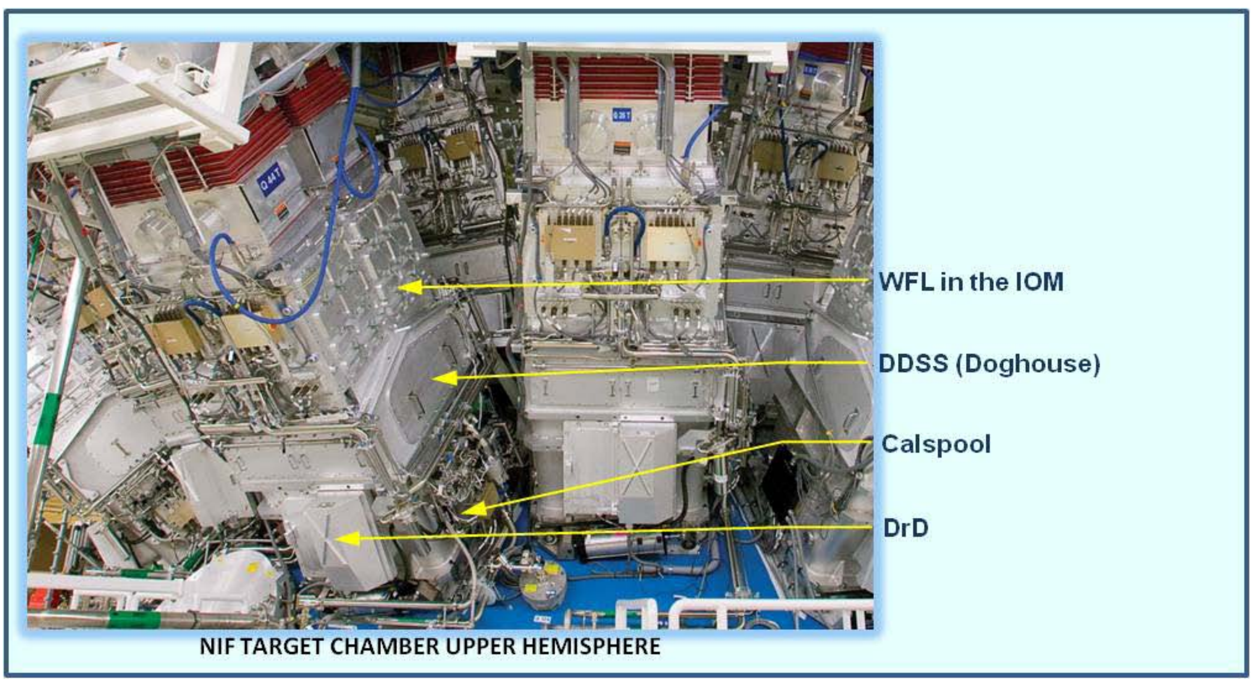

Figure 5

The Calspools were thought to be in tolerance where they were in 'Z' (along the beamline) to other assemblies where 'Z' was soft but to the WFL where 'Z' was critical 'Z' was out of tolerance. Therefore in a Global CS sense the Calspools were good enough but in a Local CS sense -as a subassembly relating to the WFL- all 48 were out of spec in 'Z' moreover could the KMA plates be accurately positioned in Local CS "X & Y; the clear aperture tolerance was looser than the DrD positional tolerance. In the Calspools current position if the DrD's were installed in the Global CS the installations would be too far in 'Z' from the WFL and "X & Y" were unknown.

The original alignment strategy involved installing the KMA plates onto the Calspools and aligning each of the 24 kinematic mounts (KM) individually; 12 on top and 12 on the bottom. Lines of sight of the more logistically difficult ports would involve looking through some of the Calspools and Doghouses, predominantly those near the north and south poles. The flaw of the strategy was the ability to obtain adequate lines of sight (LOS) to both the control network and each of the 12 KM's on each plate. This later became obvious when in many cases (as the DrD was postponed) the target building was being populated with other scheduled assemblies obstructing LOS to the network and to the KMA plates. The new strategy would need to overcome the LOS obstacle and be robust enough to logistically not impede the installation of other mechanical subsystems already scheduled in with the scaffolding and rigging needed to install the KMA plates. The best solution was a "Plug & Play" strategy. This strategy would require a compilation of as-built-and-design data to employ reverse engineering. Moreover to quality control the flow of data, their calculations and coordinate transformation would need to be both flawless and seamlessly traceable back to the OCD in order for the DrD to successfully complete commissioning for operation. Any mistake in the calculations would cause the whole process to become suspect and halt the alignments and installations; thus there would be no diagnostic for the 3Ω light just before it entered the target chamber and perhaps postponing laser experiments, therefore data quality control was paramount.

3. The Alignment Strategy

The solution to overcome the spacer concern was to relate the installation of the DrD to the WFL and generate the design and as-built coordinates in the IOM Local CS treating the relationship of the DrD to the WFL as two subassemblies integrating into an upper assembly in situ as opposed to the DrD installing into the top assembly Global CS, in summary employ a "relative alignment."

To accomplish the goal of a Plug & Play installation while not impeding other scheduled installations the KMA plates were pre-aligned in six degrees of freedom (6 DOF) offline and simply brought into their quad location and bolted in to within ±125 microns of their positional requirements.

To quality control the generation of the design data a parametric Local CS of the IOM and the Calspool interface was used to translate from port to port. Here the Local CS could be rotated and pointed to Target Chamber Center. By using the IOM Local CS -and orienting it in this attitude and vector- a gain in quality control of the design data and acquisition of the as-built data was obtained because of the symmetry of the coordinate data related to the mechanical configuration. As the metrology teams moved from port to port in the Local CS the values would reveal a symmetric pattern and assist in error detection as familiarity with the naming convention and their associated coordinate values became repetitive.

The alignment strategy used for the installation was designed to use the as-built condition of the critical interfaces on the “Calspools side” to generate the offline pre-alignment coordinates of the “KMA plate side” of the interface for alignment on a CMM.

The vertical adjustments of the mounts were related to the plane interface of the Calspools (the primary datum adjustment); their adjustments were controlled by the threaded shafts below the mounts and secured by a lock nut at the base. The lateral adjustments were related to the openings of the Calspools (the secondary and tertiary datum adjustments); their adjustments were controlled by eccentric cam hard stops and secured by four lock screws, see figure 6.

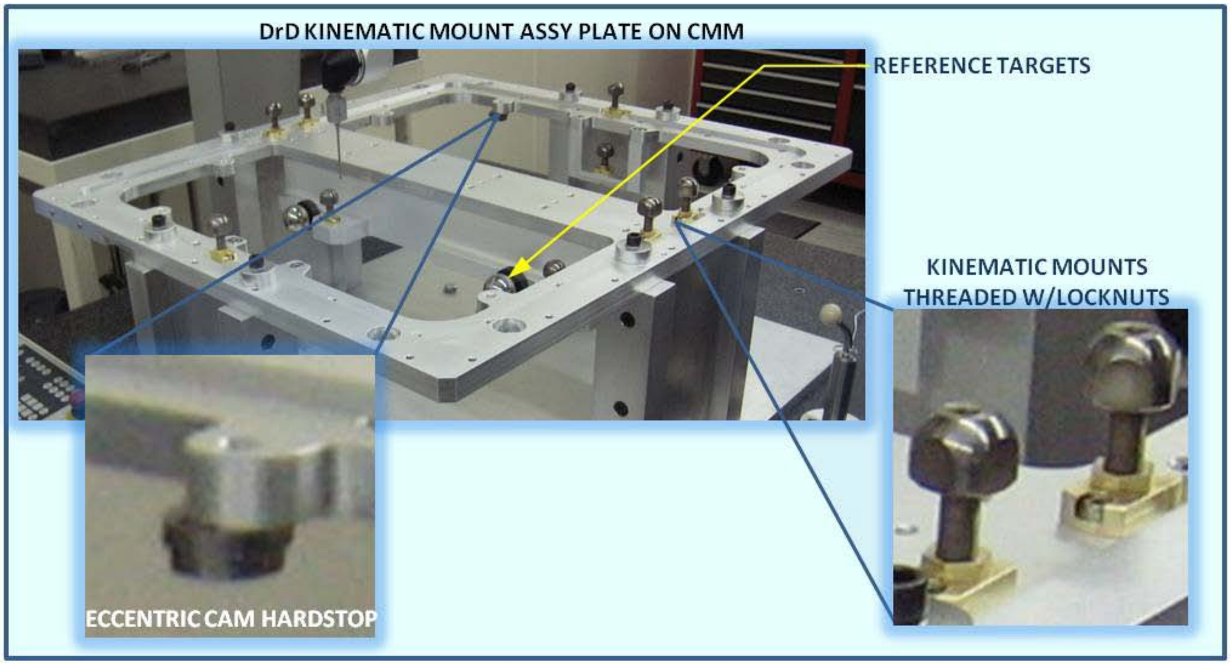

Figure 6

4. Acquisition of the As-built Data

First the critical features were identified and assigned a naming convention. Once the features and naming convention were complete the Global coordinates were generated and transformed to the IOM Local CS then the verification process validating resulting values were completed with associated drawings and procedures. The metrology teams were sent out into the Target building and were given the local coordinates with the origin along the port centerline. As they moved around the chamber taking data they would reacquire the Global CS network and transform to that specific port’s IOM Local CS. By working in the IOM Local CS the metrologist gained familiarity with the numbers; increasing possible error detection when correcting for target thicknesses. In addition to measuring the plane, the bolt-hole centers were also targeted. Characterizing the bolt centers assured there would be enough lateral translation within the through-hole’s diameter.

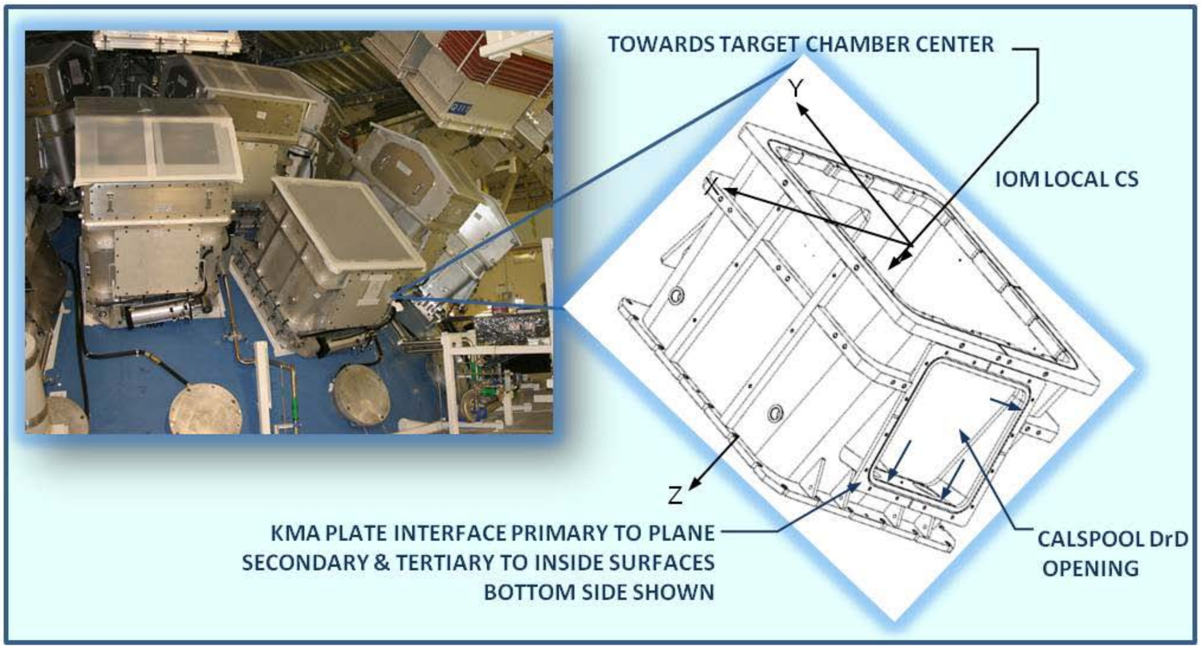

Figure 7

Later during the analysis if more adjustability was needed the through-holes could be opened up to their least material condition freeing up more lateral adjustment.

Mimicking the cam interfaces with the metrology targeting also proved invaluable. During the field measurements it was discovered the design of the eccentric cams required modification. Around the openings of the Calspools weld puddles were discovered encroaching into the cam interface envelope; in addition, during characterization in the Target Building the metrology teams were instructed to select as the secondary plane the gravity side of the Calspool DrD opening. The KMA plate weighs 64lbs therefore using gravity during installation would prevent the plate from sliding towards gravity had the upper interfaces been used, see figure 7.

As data was collected implementation to modify the as-built distances from the WFL began. This new data set would now be used to pre-align the KMA mounts and adjust the cams to the hard interface of the opening of the Calspools.

The calculations involved determining the height adjustment of the KM's 12ea. and the lateral adjustment of the cams, 3ea per KMA plate.

5. Calculating the Height Adjustments of the Kinematic Mounts

The objective was to calculate the exact height of the 576 mounts perfectly and at the same time, because of scheduling pressures, quality assure the data delivered from the target chamber catching errors real time, particularly with respect to the how the target thickness's were removed. To do this a Local Part CS was created using the feature controls designed into the KM plate. The part's primary datum was used because it was also related to the primary interface to the Calspool, for the secondary and tertiary datums, two of the KM centers were used in the lateral directions and on the plane of the primary datum to the Calspool. Using this technique removed all the error in the secondary and tertiary datums in the manufacturing process because the secondary and tertiary datums were now at two of the twelve critical interfaces, see figure 8.

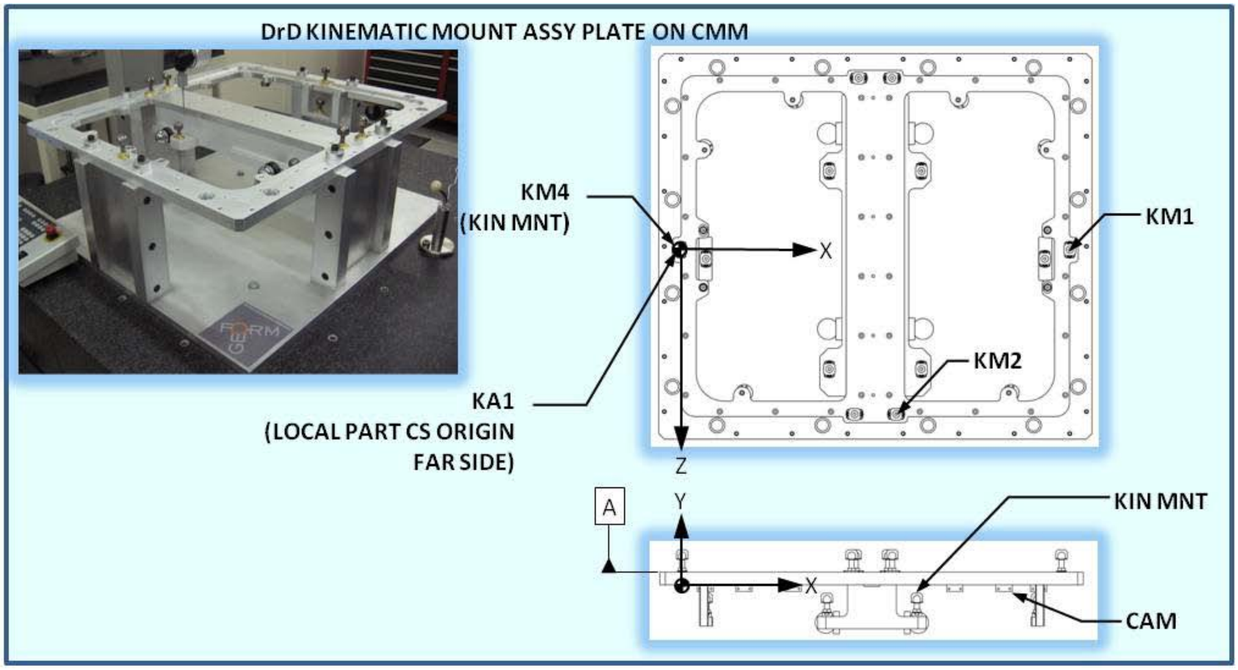

Figure 8

Now when the best-fit was applied the IOM Local CS design-data fitted to the KMA Local Part design-data and the plane as-built-data from the field metrology floated along with the fit. This technique provided two important data sets. It provided the delta vertical adjustments for the mounts and it provided the quality assurance (QA) of the Calspool plane measurements. The planes had a machined tolerance therefore an out of tolerance condition (a QA check that was designed into the data analysis) would have meant a possible error in correcting for target thickness. This QA check scrubbed out a handful of errors that if gone undetected would have led to positional errors and possibly hardware damage.

The second part of the process was to now calculate the translation offsets to be applied to the cams. The as-built data of the Calspool DrD openings from the target chamber would tell where the cam hard interfaces were by best fitting the IOM Local CS into the Part Local CS thus creating the new Part Local values. These newly created values allowed reverse engineering to be applied to create the new design values for each port location. Just as in the case of the plane fit for the KM height adjustment a QA calculation was included to detect any errors in removing target thickness's and or any other correction the field Metrologists needed to correct for. Once again the QA calculations detected a handful of errors and were corrected real-time.

6. Aligning the Kinematic Plate Offline

The field metrology was separated into two task, upper target chamber hemisphere and lower. Upon the completion of the first the data for offline alignment was created. At this point it's notable to mention a Master KMA plate was created and aligned to design values within 25 microns. This Master plate was sent to the LRU facility, in Boston Mass, where the integrated optics was pre-aligned. After installation of the KMA plates the pre-aligned LRU's could then be placed on any quad on the Target Chamber and be ready for operation. This is the main point of the LRU design, an LRU can be placed anywhere on the chamber provided the KM's are properly aligned.

The production KMA plates were sent to a metrology lab in southern California and pre-aligned using a Coordinate Measuring Machine (CMM.) The KMA plates were set up on the CMM using a custom fixture designed by the metrology lab to mimic the hold down of the plates onto the Calspools. (A duplicate tool was produced as well and kept at NIF for verification purposes.) Reference targets were also installed onto the plates. These reference targets were characterized at final inspection and were later used to verify the position of the KMA plates relating the KM's to the reference targets after installation, see figure 6 & 7.

Figure 9

7. The Installation

The installation onto the target chamber was flawless. The "Plug and Play" alignment strategy was a success. As the KMA plates were received from southern California they were immediately installed. The KMA plates would interface to the plane of the Calspool, rest on the two cams on the gravity side and slid over to the remaining cam to stop, Primary-Secondary-Tertiary, an elegant strategy. When the LRU was ready for installation it was ready to bolt up onto the kinematic mounts. As the KMA plates were installed quality assurance verifications were performed by sampling the first few installed; their positional errors were on average 80 microns. Engineering was convinced and sampling discontinued. For the most part all 192 diagnostics performed well within specifications.

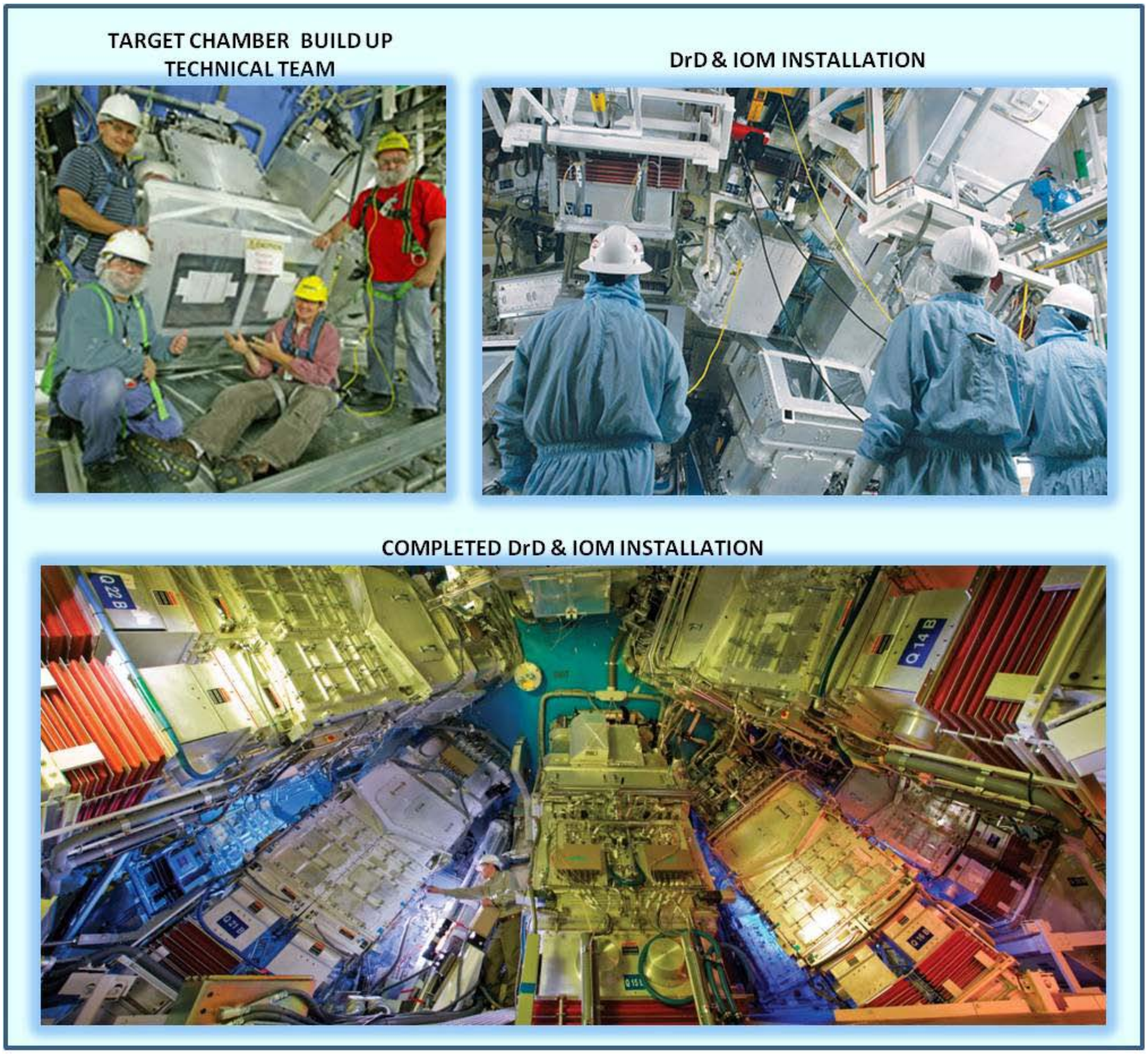

Figure 10

Auspices

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